NASA CONTRACTOR REPORT

NASA CR-1191

NASA CR-119[illegible]

OPTICAL ABSORPTION AND FLUORESCENCE IN FUSED SILICA DURING TRIGA PULSE IRRADIATION

by R. Gagosz and J. Waters

Prepared by
UNITED AIRCRAFT CORPORATION
East Hartford, Conn.

for

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION • WASHINGTON, D. C. • SEPTEMBER 1968

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Issued by Originator as Report G-910485-3

Prepared under Contract No. NASw-847 by
UNITED AIRCRAFT CORP~~ORATION~~
East Hartford, Conn.

for

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

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FOREWORD

An exploratory experimental and theoretical investigation of gaseous nuclear rocket technology is being conducted by the United Aircraft Corporation Research Laboratories under Contract NASw-847 with the joint AEC-NASA Space Nuclear Propulsion Office. The Technical Supervisor of the Contract for NASA is Captain C. E. Franklin (USAF). Results of the investigation of the characteristics of a coaxial-flow reactor conducted during the period between September 15, 1966 and April 15, 1968, and results of investigations of the characteristics of transparent materials conducted between September 15, 1967 and April 15, 1968, are described in the following two reports (including the present report) which comprise the required seventh Interim Summary Technical Report under the Contract:

1. Johnson, B. V.: Experimental Study of Multi-Component Coaxial-Flow Jets in Short Chambers. United Aircraft Research Laboratories Report G-910091-16, April 1968. (NASA CR-1190)

2. Gagosz, R. M. and J. Waters: Optical Absorption and Fluorescence in Fused Silica During TRIGA Pulse Irradiation. United Aircraft Research Laboratories Report G-910485-3, April 1968. (present report)

Optical Absorption and Fluorescence
in Fused Silica during TRIGA Pulse Irradiation

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Optical Absorption and Fluorescence in

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SUMMARY

An experimental investigation was conducted at the University of Illinois' TRIGA Mark II pulse reactor to determine the spectral transmission characteristics during and after an irradiation pulse and to determine the cause of the apparent increase in transmission during the pulse and the apparent decrease of transmission after the pulse which had been observed in the previous test program. A total of 91 experiments were performed on six specimens at a range of temperatures from 500 to 900C. Transmission measurements were made at two wavelengths, 2150 and 3021 Angstroms. Corning 7940 fused silica specimens in a corner cube configuration were mounted next to the reactor core face at the internal end of a reactor beam port. Peak neutron and gamma fluxes obtained from this reactor were approximately 5.4×10^{15} n/cm^2-sec and 6.1×10^7 R/sec, respectively. Neutron and gamma doses associated with these pulses were 2.3×10^{14} n/cm^2 and 2.0×10^6R, respectively. In addition to the transmittance tests, bypass and optical instrumentation tests were conducted to examine the influence of the optical alignment parameters upon system operation. Fluorescent tests were also conducted to obtain an applicable correction to the transmittance runs.

RESULTS

1. During the peak of the reactor pulse approximately 0.01 cm^{-1} of absorption is present at specimen temperatures of 900C.

2. Sample fluorescence, monitored alternately with transmittance tests, indicated that:

   a) at a given temperature the fluorescence is repeatable and not influenced by previous irradiation pulses;

   b) the fluorescent level decreases as the temperature is increased to 900C; and,

   c) dependent upon source intensity, the fluorescent signal can contribute significantly to the transmitted signal thereby explaining the inadequate correction of data reported previously.

3. The cause for the apparent transmission decrease 150 milliseconds after the irradiation pulse has not been conclusively determined, but is still felt to be due to uneven cooling of the specimen, which is gamma-heated during the pulse.

4. Improved shielding of the experimental equipment minimized the influence of gamma irradiation on the photomultiplier, thereby removing the need for bypass corrections.

INTRODUCTION

A program is being conducted at the Research Laboratories of United Aircraft Corporation under Contract NASw-847 with the Joint AEC-NASA Space Nuclear Propulsion Office to determine the feasibility of the nuclear light bulb rocket engine concept. This engine concept is based on the transfer of energy by thermal radiation from gaseous nuclear fuel through an internally cooled transparent wall to a seeded hydrogen propellant. The degree of transparency of the wall will depend upon two competing factors: 1) the creation of color within the wall due to the nuclear irradiation and, 2) the bleaching and/or annealing of this irradiation-induced color at elevated wall temperatures. The engine concept requires that the wall temperature be sufficiently high to maintain transparency when subjected to the intense neutron and gamma irradiation during engine operation.

Several programs have been conducted to determine the effect of nuclear irradiation on the transmission characteristics of optical materials. The purpose of these investigations has been to determine the equilibrium absorption which may be present in the wall of an operating nuclear light bulb engine by examining the relationship between the reactor irradiation parameters (flux and dose) and material temperature. Since it is not possible to simulate both the neutron flux and neutron dose of an operating nuclear light bulb in a single irradiation under reactor operating conditions, the research investigations have been carried out using two different techniques to simulate, independently, dose and flux in a nuclear light bulb engine. Dose simulation was accomplished by measuring the optical transmission of materials subsequent to long reactor irradiations (Refs. 1 and 2). Flux simulation was accomplished by measuring the optical transmission of materials during exposure to the nuclear irradiation in a pulsed reactor with high peak power levels (Ref. 3).

During the flux simulation studies, two anomalies were noted. First, there was an indicated increase in the transmission (negative absorption) of the fused silica during the reactor pulse; this was presumably due to sample fluorescence or gamma irradiation effects on the light source or photomultiplier systems. Second, there was an apparent decrease in transmission approximately 150 milliseconds after the reactor pulse; this effect, which disappeared several seconds after the reactor pulse was thought to be the result of non-uniform temperature gradients due to gamma heating of the sample during the reactor pulse. These two effects are illustrated in Fig. 1 (data of Ref. 3) and are dominant at elevated temperatures (500 and 900C).

Consequently, the in-reactor irradiation test program at the University of Illinois TRIGA Mark II reactor was continued using modifications to the basic techniques which were employed previously. Since the anomalies noted above were apparent only in the ultraviolet portion of the spectrum, testing was restricted to two wavelengths: 2150 Angstroms, the center of a neutron-induced absorption band; and 3021 Angstroms, an arbitrary ultraviolet wavelength not associated with any neutron induced absorption band. Measurements were made of the transmission characteristics of fused silica immediately before, during and after the reactor pulses. In addition tests were conducted to determine the cause of the anomalous results described above. These included shielding tests, optical instrumentation tests and fluorescent tests. Specimen temperatures ranged from 500 to 900C with the majority of the tests being conducted at 700C.

DESCRIPTION OF EQUIPMENT

System Configuration

The optical instrumentation system employed in the present test program is the same as that used in the previous programs (Ref. 3). It is capable of making transmission measurements during the TRIGA pulse at any selected wavelength from 0.21 to 1.1 microns at specimen temperatures ranging from ambient to 900C with an overall response time of 3 milliseconds and an accuracy of ±5%. The optical configuration of the instrument is presented schematically in Fig. 2, and pictorially in Fig. 3. As indicated in the figure, optical radiation, selected from either of two light sources, passes through a condensing system which serves to collect the radiation and focus it on a variable aperture which acts as a point source for the collimating optics. The light is then collimated using an off-axis parabolic first surface mirror (Perkin-Elmer 098-0041) and directed towards the specimen located in the nuclear environment using a 45° prism silvered on the two perpendicular faces. A variable field stop is present in the collimating system in order to limit the amount of light received by the specimen. The specimen itself is a corner cube prism made of Corning 7940 U.V. grade fused silica and is mounted within a water cooled furnace assembly located at the internal end of the beam port next to the reactor core face. In traversing the specimen, the light is internally reflected such that it is redirected out of the nuclear environment parallel to, but laterally displaced from, the incoming beam (an inherent characteristic of the corner cube configuration). The light then strikes the second silvered face of the 45° prism and is directed towards a second off-axis parabolic mirror (Perkin-Elmer 098-0041) which focuses the light on the entrance slit of the monochromator (Perkin-Elmer 99) and detector subsystem via an auxiliary first surface mirror. In order to obtain rapid data acquisition of transient effects, a Visicorder, equipped with 500 KC galvanometers, is employed to record the output from the detector subsystem.

Also shown in Figs. 2 and 3 are the concrete and lead shielding walls installed prior to the present series of test to minimize the effects of gamma irradiation on the photomultiplier.

In the present investigations, concerned only with the ultraviolet spectral region, the Hanovia 771-B-32 hydrogen discharge lamp was used in combination with a modified Cary 1P28 photomultiplier detector. The hydrogen discharge lamp with two permanently mounted Suprasil windows provides ample energy in the ultraviolet down to 0.16 microns. It was determined prior to investigation of the present test program that the hydrogen discharge lamps, as received from the manufacturer, were very unstable. The difficulty was traced to an incorrect pressure of hydrogen within the lamp and subsequent refilling of the lamps appeared to correct the problem. However, some instability and short operating life-times were still experienced during the first group of tests (Series A through D) conducted at the reactor test site. This problem was corrected before the second group of tests (Series E through H) by operating the lamps for thirty minutes with flowing hydrogen at 5 m.m. pressure prior to sealing. This procedure improved lamp operation by increasing both the stability and the output intensity.

EXPERIMENTAL TEST PROGRAM

The experimental test program was designed to accomplish several objectives:

1. To verify that the apparent increase in transmission during the irradiation pulse was in part caused by an interaction of the reactor pulse upon the instrumentation and correct the problem.

2. To examine the fluorescence, if any, of the sample, during the reactor irradiation.

3. To determine the cause of the apparent loss in transmission shortly after the reactor pulse.

4. To determine the amount of absorption present in the specimen during the reactor pulse. (It should be noted that while this was the main objective of the present program, it was first necessary to account for the anomalies observed in the previous program.)

The University of Illinois TRIGA Mark II reactor was operated in the pulse mode to obtain the high peak powers ($>$ 500 Megawatts) generated in this mode. Pulses at this power level supply peak neutron and gamma fluxes of approximately 5.4×10^{15} n/cm^2-sec and 6.7×10^7R/sec respectively with a pulse width at half peak power of approximately 30 milliseconds. Total integrated neutron and gamma doses provided by the reactor were on the order of 2.3×10^{14} n/cm^2 and 2.6×10^6R respectively.

A total of 91 reactor pulses were performed using a total of 6 specimens. The test conditions for these pulse irradiation are summarized in Table I.

Bypass Tests - Fourteen runs were made to study the effect of the pulse irradiation on the instrumentation; the light beam bypassed the reactor or the monochromator entrance slit was closed for these runs.

Fluorescent Tests - Twenty five runs were made to monitor the fluorescent radiation during a pulse; the light source remained off for these runs.

Instrumentation Tests - Twenty runs were made to determine the effects of optical alignment upon the apparent transmission decrease some 150 milliseconds after the peak of the pulse, and six runs were made in an attempt to visually determine, by schlieren observation, causes for this apparent transmission decrease.

Transmissivity Tests - Twenty six runs were made to obtain transmission data; these runs were alternated with the fluorescent runs to determine correction factors.

Bypass Tests

Eleven bypass runs (A-1 through A-11) were made to determine whether the reactor pulse had any effect on the instrumentation and, if so, to establish corrective measures. These tests are summarized in Table II. It was determined during the first two of these runs that gamma radiation, rather than light source effects, was the cause of the noise signal within the photomultiplier. Therefore, nine of the eleven runs were conducted with the monochromator entrance slit closed to eliminate both light source and ambient light effects. Three additional runs were made throughout the program to verify the effectiveness of the corrective measures which are discussed below.

Figure 4 shows the effect of photomultiplier location. The complete absence of any increase in signal during a reactor pulse when the photomultiplier was located outside the shielding concrete wall indicated that the beam catcher (located on the axis of the beam port) was backscattering the gamma-radiation to the photomultiplier. As a result of these tests, the beam catcher was repositioned and a new concrete and lead wall was installed (Figs. 2 and 3) to reduce the back-scattered radiation intercepted by the photomultiplier. Additional lead shielding was used around the photomultiplier. Figure 5 shows the improvement in noise signal (reduction) as a result of installation and modification of this shielding. In this case, the runs were made with the light source on, thus accounting for the increased signal level over that shown in Fig. 4, and the light beam bypassing the reactor beam port.

Further studies were conducted during this series of bypass tests to verify the use of the subtractive corrections applied to the data of the previous contract (Ref. 3). These studies showed that the change in photomultiplier output, as a function of gain, was identical for both gamma induced noise and a constant intensity light source; thus substantiating that the noise is additive.

Fluorescent Tests

A total of twenty-five fluorescent runs were made at temperatures ranging from 500 to 900C. The fluorescence was detected by monitoring the energy incident upon the entrance slit of the monochromator with the light source off. Thus the only light collected and detected would be that radiated by the specimen during the pulse. The monochromator slit width was the same for both the fluorescence and transmittance tests. These tests show that significant specimen fluorescence occurs during the reactor pulse. Figures 6 through 8 show typical fluorescent signals obtained in run series B, C and G.

The repeatability of the fluorescence at a specimen temperature of 700C is shown in Fig. 6. This degree of repeatability indicates that there is no increase of fluorescence with successive irradiation pulses and, therefore, allows direct subtraction of the fluorescence from the transmittance runs. The effect of temperature on the fluorescent level is shown in Figs. 7 and 8. In both cases, a 25 to 30% reduction in the magnitude of the fluorescence occurs as the temperature is increased from 500 to 900C. This reduction is significantly larger than the scatter shown in Fig. 6, indicating that reduced fluorescence with increased temperature is a real effect.

The magnitude of the fluorescent signal (in some cases equal to the transmitted signal) explains the apparent anomaly of increased transmission observed during the previous contract and reported in Ref. 3. No fluorescent measurements were made in that program and therefore, a complete correction could not be made.

Instrumentation Tests

Twenty instrumentation test runs were conducted to determine the cause of the second anomaly (the apparent decrease in transmission some 150 milliseconds after the reactor pulse) noted in the introduction. These runs are summarized in Table III. The effect of optical parameters was studied first, by varying the monochromator slit width, the focus of the monochromator, the focus of the condensing parabola immediately preceding the monochromator and the alignment of the optical beam with respect to the optic axis of the system. As shown in Table III, no large changes (greater than 5%) in the level of the transmitted signal were observed during these test runs. The apparent transmission decrease was, therefore, interpreted to be insensitive to the optical alignment parameters.

The cause of the apparent loss in transmission was then assumed to be the result of the light beam deviating from the optical axis in traversing the corner cube specimen. Such deviations could be caused by thermal gradients within the corner cube which are induced by gamma-ray heating and subsequent cooling of the specimen after the reactor pulse. Heat can be conducted out of the specimen through the aluminum oxide holder which is in contact with the specimen at three points (equally spaced 120^{o} apart) on the circular portion of the corner cube. Figure 9 shows the effect of modifying the heat conduction path from the specimen. In one case (run E-1) all three specimen contacts were in place whereas one of the contacts was deliberately broken in run F-1. The optical alignment was the same in these two runs and the significant difference in the transmissivity indicates that the apparent loss of transmission in the specimen after the reactor pulse is not due to real absorption, but possibly to a dispersive effect on the light beam as a result of a thermal gradient.

Six high speed schlieren movies were also taken during this testing period in an attempt to verify the above conclusion. These tests were made using the visible spectrum from the tungsten strip filament lamp since high speed film sensitivity is not available at 2150Å in the ultraviolet. However, the results were somewhat inconclusive since it was not possible to obtain good film exposure. In addition, the effect would not be as easily observable in the visible region where the dispersion (the variation of index of refraction with wavelength) of fused silica is quite small. On the contrary, the dispersion in the ultraviolet region would be quite large, since the wavelength of observation is very close to the absorption edge of fused silica, especially at elevated temperatures. Consequently, small perturbations in specimen temperature could cause significant effects on beam propagation in the ultraviolet, but no conclusive results were obtained to substantiate this postulated explanation for the second anomaly.

Transmissivity Tests

Twenty-six irradiation pulses were made to obtain specimen transmissivity data during and immediately after the pulse. A total of four specimens was used for this portion of the program. Specimen temperatures ranged from 500 to 900C with the majority of runs being made at 700C. Two specimens (SC62-8 and SC62-9) were not annealed prior to the irradiation process while the two other specimens (SC62-11 and SC62-13) were annealed at 1050C (higher than any in-reactor temperature) for one hour prior to testing in the reactor beam port.

Figure 10 illustrates typical data obtained with the Visicorder during runs G-3 and G-4. The transmission run, G-3, shows a peak-to-peak fluctuation of approximately 4% and therefore limits the sensitivity of the measurements (the 4% fluctuation corresponds to an absorption coefficient of approximately 0.005 cm^{-1}). The fluorescent run, G-4, when compared with run G-3, shows the magnitude of the fluorescence relative to the transmitted signal level during the peak of the pulse. The data obtained during these two runs is plotted at 10 millisecond intervals during the peak of the pulse as shown in Fig. 11 to illustrate the manner in which the data was reduced. The fluorescent signal level recorded in run G-4 has been subtracted from the signal level of the transmission run (G-3) to obtain the corrected signal level during the peak of the pulse. The correction is only applicable during the peak of the pulse (the period of strong fluorescence). The transmissivity of the specimen during and after the irradiation can be subsequently obtained by taking the ratio of the corrected signal level, I_t, at times during and after the pulse, to the signal level, $I_{-0.1}$, 0.1 seconds before the peak of the pulse. The corrected transmissivity along with the irradiation induced absorption coefficient, for the various data runs is plotted as a function of time from the peak of the pulse in Figs. 12 through 18.

The transmissivity of the unannealed specimen, SC62-8, at 3021 Angstroms is shown in Fig. 12 for 3 different specimen temperatures: 500, 700 and 900C. Because the difference in transmissivity for these three runs is less than the 5% sensitivity of the system, no differences between the runs can be detected and attributed to effects of specimen temperature. A variation in the transmissivity of this same specimen at 2150 Angstroms, as a function of temperature, can be seen in Fig. 13. The apparent increase in transmissivity at the peak of the pulse during run B-18 (900C) is attributed to an instability in the hydrogen lamp output near the end of its operating life.

The repeatability of the data during runs at 700C for an annealed sample (SC62-11) and an unannealed sample (SC62-9) is illustrated in Figs. 14 and 15 respectively. The shape of the curves obtained in the two tests are similar with the unannealed specimen having approximately a 10% greater loss in transmissivity during the pulse. As can be seen by comparing the Tables in Figs. 14 and 15 a larger (by a factor of 2) fluorescent correction was required during series D. This was due to a decrease in lamp intensity during this set of runs with the result that the fluorescent signal level was approximately equal to the transmitted lamp intensity.

Figures 16 through 18 illustrate the transmissivity results obtained using an annealed specimen, SC62-13, at temperatures of 500, 700 and 900C. The lamp intensity and stability were sufficiently improved for these runs so as to reduce the relative magnitude of the fluorescence at the peak of the pulse to 4 to 8% of the transmitted signal. As a result, it is felt that this data is most representative of the transient absorption induced within the specimen during the irradiation pulses. The maximum amount of absorption, 0.02 cm^{-1} at 500C and 0.01 cm^{-1} at 900C, occurs approximately 10 milliseconds after the peak of the pulse.

The effect of temperature on the absorption coefficient during the peak of the TRIGA pulse for all data runs is summarized in Table IV and presented graphically in Fig. 19. Although a considerable amount of scatter exists as a result of lamp intensity fluctuations, careful examination of the data obtained during run series G shows an absorption coefficient of about 0.015 cm^{-1} at 500C which decreases linearly to 0.010 cm^{-1} at 900C. It is felt that this amount of absorption should not adversely affect the operation of a nuclear light bulb engine.

STUDY OF FUTURE IN-REACTOR EXPERIMENTS

Preliminary studies have been conducted to examine the possibility of measuring the transmission of optical specimens while they are exposed to steady state irradiation in either Union Carbide's 5 Megawatt steady state reactor or a Dynamitron electron accelerator. Such investigations would, in the first case, permit an examination of the absorption produced in a material under long term exposure to a continuous flux whose total dose would simulate that of an operating nuclear light bulb engine; and, in the second case, provide very high steady-state electron fluxes in order to simulate the coloration to be expected in a nuclear light bulb engine.

Union Carbide Studies

This investigation, in addition to simulating total dose conditions, would also permit a determination of the equilibrium absorption which may exist during the irradiation. The initial studies indicate that specimen configuration used in the TRIGA experiments would also be applicable for these tests by utilizing a beam port in the Union Carbide Reactor. Some equipment modifications would be required in order to provide a reference beam for these long term (10 to 100 hours) experiments. Because of the continuous nature of this irradiation, extensive shielding, requiring review by the Reactor Safety Committee at Union Carbide, will be necessary to maintain personnel safety.

Dynamitron Studies

While it is possible, in a dynamitron accelerator, to simulate the coloration present in a nuclear light bulb engine, the difficulty in such tests lies in the problem of finding an electron flux which provides the same effect as the neutron and gamma flux. One measure of the proper flux simulation may be the ionizing dose rate since the ionizing radiation appears to be the cause of the color in the samples previously tested (Refs. 2 and 3). It has been estimated that a beam current density of 0.2 milliamperes/cm^2 (1.3×10^{15} electrons/cm^2-sec) would provide the same ionizing flux as the gamma radiation in a full scale nuclear light bulb engine. However, simulation of the displacements induced by the neutrons, which are created in a nuclear light bulb engine, would require an electron flux between one and two orders of magnitude higher than that for ionizing dose rate simulation.

An electron flux of 1.3×10^{15} electrons/cm^2-sec leads to two conditions on the thickness of the specimens which may be employed in the dynamitron tests. First, the penetration depth would depend upon the specific energy of the electrons, e.g., 1.42 Mev electrons penetrate to a depth of approximately 0.364 cm. which sets the maximum allowable thickness. Second, the high heat deposition may lead to a large temperature gradient across the sample. Since this temperature difference increases approximately as the square of the thickness of the specimen, it would be desirable to employ as thin a specimen as possible, consistent with instrumental considerations. To limit the temperature differential to 110C, the maximum thickness allowed is 0.12 cm when the back surface (side opposite the electron beam) of the specimen is cooled.

Preliminary investigations based upon this relatively thin sample dimension (0.12 cm) suggests a specimen configuration in which the back surface is cooled and the diagnostic light beam is passed through the specimen parallel to the large surfaces. This should not impose any stringent requirements on the optical configuration since any portion of the light beam striking the closely spaced parallel surfaces will undergo total internal reflection and thus not be scattered out of the specimen.

REFERENCES

1. Douglas, F. C. and R. M. Gagosz: Experimental Investigations of Thermal Annealing of Nuclear-Reactor-Induced Coloration in Fused Silica. United Aircraft Research Laboratories Report D-910082-7, March 1965. Also issued as NASA CR-304.

2. Douglas, F. C., R. Gagosz, and M. A. DeCrescenti: Optical Absorption in Transparent Materials Following High Temperature Reactor Irradiation. United Aircraft Research Laboratories Report F-910485-2, September 1967. To be issued as NASA CR Report.

3. Gagosz, R. M., J. P. Waters, F. C. Douglas, and M. A. DeCrescenti: Optical Absorption in Fused Silica during TRIGA Reactor Pulse Irradiations. United Aircraft Research Laboratories Report F-910485-1, September 1967. To be issued as NASA CR Report.

LIST OF SYMBOLS

t	Time, sec
I_t	Signal level during and after TRIGA pulse, millivolts
$I_{-0.1}$	Signal level 0.1 seconds before TRIGA pulse, millivolts
α	Absorption coefficient, cm^{-1}
τ	Transmissivity, I/I_0
τ_c	Transmissivity corrected for fluorescence

TABLE I

TRIGA TEST CONDITIONS

Run No.	Test Type	Specimen	Peak Neutron Flux, 10^{15}n/cm^2-sec	Neutron Dose, 10^{14}n/cm^2	Wavelength, Angstroms	Specimen Temperature, Degrees Centigrade	Sample Precondition	Photomultiplier Voltage	Slit Width, Millimeters	Source Conditions 10^{-3}amps	Source Conditions 10^3volts	Signal Level at t=.01 sec Millivolts	Data Presented in Figure
A-1	Bypass	None	5.52	2.29	2150	Ambient	Unannealed	700	0.40	320	1.2	304	5
A-2	"	"	5.39	2.25	"	"	"	720	0	0	0	16.4	
A-3	"	"	5.34	2.25	"	"	"	830	"	"	"	15.6	
A-4	"	"	5.32	2.25	"	"	"	680	"	"	"	0	
A-5	"	"	5.34	2.24	"	"	"	780	"	"	"	9.3	
A-6	"	"	5.42	2.24	"	"	"	730	"	"	"	3.9	4
A-7	"	"	5.40	2.27	"	"	"	730	"	"	"	18.5	4
A-8	"	"	5.42	2.27	"	"	"	730	"	"	"	29.6	
A-9	"	"	5.46	2.29	"	"	"	730	"	"	"	31.6	
A-10	"	"	5.43	2.26	"	"	"	730	"	"	"	72.3	
A-11	"	"	5.63	2.29	2150	"	"	730	0.40	320	1.2	200	5
B-1	Transmission	SC62-8	5.43	2.25	"	500	"	730	0.40	320	1.2		
B-2	"	"	5.46	2.25	"	Ambient	"	730	0.30	320	1.2		
B-3	"	"	5.46	2.26	"	500	"	710	0.40	320	1.7	210	
B-4	"	"	5.42	2.27	2160	"	"	640	0.40	230	1.7	208	
B-5	"	"	5.40	2.25	2140	"	"	640	0.40	260	1.7	150	
B-6	"	"	5.39	2.25	2160	"	"	640	0.40	260	1.7	170	
B-7	"	"	5.46	2.26	2350	"	"	640	0.40	258	1.7	210	
B-8	"	"	5.43	2.27	3021	"	"	530	0.15	258	1.7	154	
B-9	Fluorescent	"	5.43	2.26	3021	"	"	640	0.15	0	0	0	12
B-10	Bypass	"	5.40	2.26	3021	"	"	"	0	"	"	"	
B-11	Fluorescent	"	5.40	2.26	2150	"	"	"	0.40	"	"	0	
B-12	Transmission	"	5.40	2.27	2150	"	"	"	0.40	258	1.6	90	7
B-13	Fluorescent	"	5.40	2.26	2150	700	"	"	0.40	0	0	0	13, 19
B-14	Transmission	"	5.37	2.25	2150	"	"	"	0.40	258	1.7	62.5	7
B-15	Fluorescent	"	5.37	2.25	3021	"	"	"	0.15	0	0	0	13, 19
B-16	Transmission	"	5.34	2.25	3021	"	"	"	0.15	260	1.7	91.0	12
B-17	Fluorescent	"	5.34	2.25	2150	900	"	"	0.40	0	0	0	
B-18	Transmission	"	5.36	2.25	2150	"	"	"	0.40	255	1.7	21	7
B-19	Fluorescent	"	5.33	2.25	3021	"	"	"	0.15	0	0	0	13, 19
B-20	Transmission	"	5.34	2.25	3021	"	"	"	0.15	255	1.7	65	
B-21	Fluorescent	"	5.30	2.23	2150	"	"	"	0.40	0	0	0	12
B-22	Bypass	"	5.28	2.23	"	"	"	"	0.40	260	1.7	0	
B-23	Fluorescent	"	5.45	2.30	"	700	"	"	0.40	0	0	0	
C-1	Fluorescent	SC62-11	5.55	2.27	"	"	Annealed*	690	0.40	0	0	0	6
C-2	Bypass	"	5.43	2.29	"	"	"	"	0	0	0	0	
C-3	Transmission	"	5.46	2.28	"	"	"	"	0.40	260	1.7	61	14, 19
C-4	Fluorescent	"	5.46	2.27	"	"	"	"	"	0	0	0	6
C-5	Transmission	"	5.46	2.30	"	"	"	"	"	260	1.7	61	14, 19
C-6	Fluorescent	"	5.48	2.29	"	"	"	"	"	0	0	0	6
C-7	Transmission	"	5.46	2.25	"	"	"	"	"	260	1.7	59	14, 19
C-8	Fluorescent	"	5.46	2.29	"	"	"	"	"	0	0	0	6
C-9	Transmission	"	5.46	2.29	"	"	"	"	"	265	1.75	67	14, 19
D-1	Fluorescent	SC62-9	5.45	2.29	"	"	Unannealed	"	"	0	0	0	
D-2	Transmission	"	5.43	2.27	"	"	"	"	"	260	1.8	40	15, 19
D-3	Fluorescent	"	5.43	2.27	"	"	"	"	"	0	0	0	
D-4	Transmission	"	5.40	2.27	"	"	"	"	"	260	1.8	25.5	15, 19
D-5	Fluorescent	"	5.40	2.26	"	"	"	"	"	0	0	0	
D-6	Transmission	"	5.37	2.26	"	"	"	"	"	260	1.9	26.5	15, 19
D-7	Fluorescent	"	5.40	2.25	"	"	"	"	"	0	0	0	
D-8	Transmission	"	5.40	2.29	"	"	"	"	"	260	2.0	23	15, 19
D-9	Photo-optical	"	5.46	2.29	(Visible)	"	"	-	-	-	-	-	
D-10	"	"	5.44	2.26	"	"	"	-	-	-	-	-	
D-11	"	"	5.43	2.26	"	"	"	-	-	-	-	-	
D-12	"	"	5.41	2.28	"	"	"	-	-	-	-	-	
E-1	Transmission	SC62-12	5.07	2.15	2150	700	Annealed	690	0.40	300	1.55	100	9
E-2	Transmission	"	5.10	2.16	"	"	"	690	0.40	300	1.55	89	
E-3	Transmission	"	5.12	2.18	"	"	"	690	0.40	300	1.55	94	
E-4	Fluorescent	"	5.04	2.17	"	"	"	690	0.40	0	0	0	
E-5	Transmission	"	5.03	2.14	"	"	"	590	0.80	300	1.55	138	
E-6	Fluorescent	"	5.04	2.14	"	"	"	590	0.80	0	0	0	
E-7	Transmission	"	4.98	2.15	"	"	"	590	1.2	300	1.55	296	
E-8	Fluorescent	"	5.04	2.14	"	"	"	590	1.2	0	0	0	
E-9	Transmission	"	4.99	2.15	"	"	"	490	2.0	300	1.55	140	
E-10	Fluorescent	"	4.99	2.13	"	"	"	490	2.0	0	0	0	
E-11	Transmission	"	5.05	2.15	"	"	"	690	0.40	300	1.55	84	
E-12	"	"	5.02	2.13	"	"	"	"	0.40	"	"	169	
E-13	"	"	5.30	2.21	"	"	"	"	"	"	"	203	
E-14	"	"	5.28	2.21	"	"	"	"	"	"	"	187	
E-15	"	"	5.30	2.20	"	"	"	"	"	"	"	270	
E-16	"	"	5.28	2.20	"	"	"	"	"	"	"	187	
E-17	"	"	5.25	2.20	"	"	"	"	"	"	"	68.5	
E-18	"	"	5.24	2.20	"	"	"	"	"	"	"	53	
E-19	"	"	5.25	2.08	"	"	"	"	"	"	"	51	
E-20	"	"	7.14	2.23	"	"	"	"	"	"	"	51	
E-21	"	"	5.29	2.05	"	"	"	"	"	"	"	101	
F-1	"	SC62-10	5.22	2.20	"	"	Unannealed	"	"	"	"	118	9
F-2	"	SC62-10	5.22	2.20	"	"	"	"	"	"	"	68	
F-3	"	SC62-10	5.21	2.20	"	"	"	"	"	"	"	170	
G-1	"	SC62-13	5.21	2.16	"	500	Annealed	"	"	"	"	168	16, 18, 19
G-2	Fluorescent	"	5.21	2.15	"	500	"	"	"	0	0	0	8
G-3	Transmission	"	5.25	2.10	"	700	"	"	"	300	1.55	160	10, 11, 18, 19
G-4	Fluorescent	"	5.19	2.18	"	700	"	"	"	0	0	0	8, 10, 11
G-5	Transmission	"	5.19	2.18	"	900	"	"	"	300	1.55	72.5	17, 18, 19
G-6	Fluorescent	"	5.19	2.16	"	900	"	"	"	0	0	0	8
G-7	Transmission	"	5.21	2.18	"	900	"	"	"	300	1.55	70.3	17, 19
G-8	Fluorescent	"	5.21	2.18	"	900	"	"	"	0	0	0	8
G-9	Transmission	"	5.19	2.18	"	500	"	"	"	300	1.55	161	16, 19
G-10	Fluorescent	"	5.16	2.15	"	500	"	"	"	0	0	0	8
H-1	Photo-optical	"	5.19	2.18	(Visible)	700	"	-	-	-	-	-	
H-2	Photo-optical	"	5.22	2.18	(Visible)	700	"	-	-	-	-	-	

* Annealed at 1050°C for 1 hour

TABLE II

SUMMARY OF BYPASS TEST RESULTS

Run	Signal increase at peak of pulse	Source Current	Photomultiplier Voltage	Monochromator Slit width	Test Description
A-1	off scale	320 ma	700	0.4 mm	Normal Bypass
-2	64.3	0	730	0	Photomultiplier test
-3	off scale	0	830	0	Photomultiplier gain test
-4	36.5	0	680	0	" " "
-5	101.1	0	780	0	" " "
-6	39.3	0	730	0	Photomultiplier located at monochromator
-7	1.1	0	730	0	Photomultiplier located outside shielding wall
-8	21.9	0	730	0	Additional lead shielding provided for monochromator photomultiplier
-9	11.5	0	730	0	Beam catcher and lead window removed
-10	1.0	0	730	0	New shielding wall installed
-11	1.1	320 ma	730	0.40	Normal Bypass

TABLE III

SUMMARY OF OPTICAL-INSTRUMENTATION TESTS

Run	Transmissivity, $I_t/I_{-0.1}$ t=0.1 sec	t=0.15 sec	t=0.2 sec	Slit width, Millimeters	Parabola to entrance slit distance	Monochromator Alignment	Peak neutron flux, $10^5 n/cm^2$-sec	Neutron Dose, $10^{14} n/cm^2$	Photomultiplier Voltage	Dana Gain	Specimen	Orientation	Optical Beam Diameter
E-1	93.9%	94.6%	95.4%	0.4	f***	in focus	5.07	2.15	690	50	SC62-12		11/16"
E-2	93.5	94.0	96.5	0.4	f	in focus	5.10	2.16	690	50	"	"	"
E-3	93.3	93.3	96.4	0.4	f	in focus	5.12	2.18	690	50	"	"	"
E-4													
E-5	95.6	96.7	97.7	0.8	f	in focus	5.03	2.14	590	20	"	"	"
E-6													
E-7	95.4	96.0	97.3	1.2	f	in focus	4.98	2.15	590	20	"	"	"
E-8													
E-9	96.3	96.3	97.7	2.0	f	in focus	4.99	2.15	490	20	"	"	"
E-10													
E-11	95.4	95.4	97.0	0.4	0.5"<f	in focus	5.05	2.15	690	20	"	"	"
E-12	97.7	97.7	98.4	0.4	0.5">f	in focus	5.02	2.13	"	20	"	"	"
E-13	92.3	94.8	96.1	0.4	f	defocussed	5.30	2.21	"	20	"	"	"
E-14	96.2	97.9	99.0	0.4	0.5"<f	defocussed	5.28	2.21	"	20	"	"	"
E-15	97.9	98.6	99.8	0.4	0.5">f	defocussed	5.30	2.20	"	20	"	"	"
E-16	95.1	95.8	96.6	0.4	f	defocussed	5.28	2.20	"	20	"		"
E-17	97.0	97.7	98.6	0.4	0.5">f	in focus	5.25	2.20	"	50	"	"	"
E-18	97.0	95.5	97.0	0.4	f	in focus	5.24	2.20	"	50	"	"	3/8"
E-19	96.9	95.3	98.4	0.4	f	in focus	5.25	2.08*	"	50	"	"	3/8"
E-20	96.9	95.3	98.4	0.4	f	in focus	7.14	2.23*	"	50	"	"	3/8"
E-21	92.3	96.1	96.9	0.4	f	in focus	5.29	2.05*	"	20	"	"	3/8"**
F-1	89.0	88.8	91.2	0.4	0.5">f	in focus	5.22	2.20	"	50	SC62-10	random	11/16"
F-2	91.2	91.2	93.5	0.4	f	in focus	5.22	2.20	"	20	"	random	"
F-3	97.7	98.1	99.5	0.4	0.1">f	in focus	5.21	2.20	"	20	"	random	"

Wavelength	0.215 microns
Temperature	700°C
H_2 Source	300 ma at 1550 volts
SC62-12	preannealed - when sample was removed all cement contacts were broken
SC62-10	unannealed - one contact deliberately broken

*Control rods dropped sooner than normal
**Beam deflected slightly from optic axis
***Focal length of parabolic mirror

TABLE IV

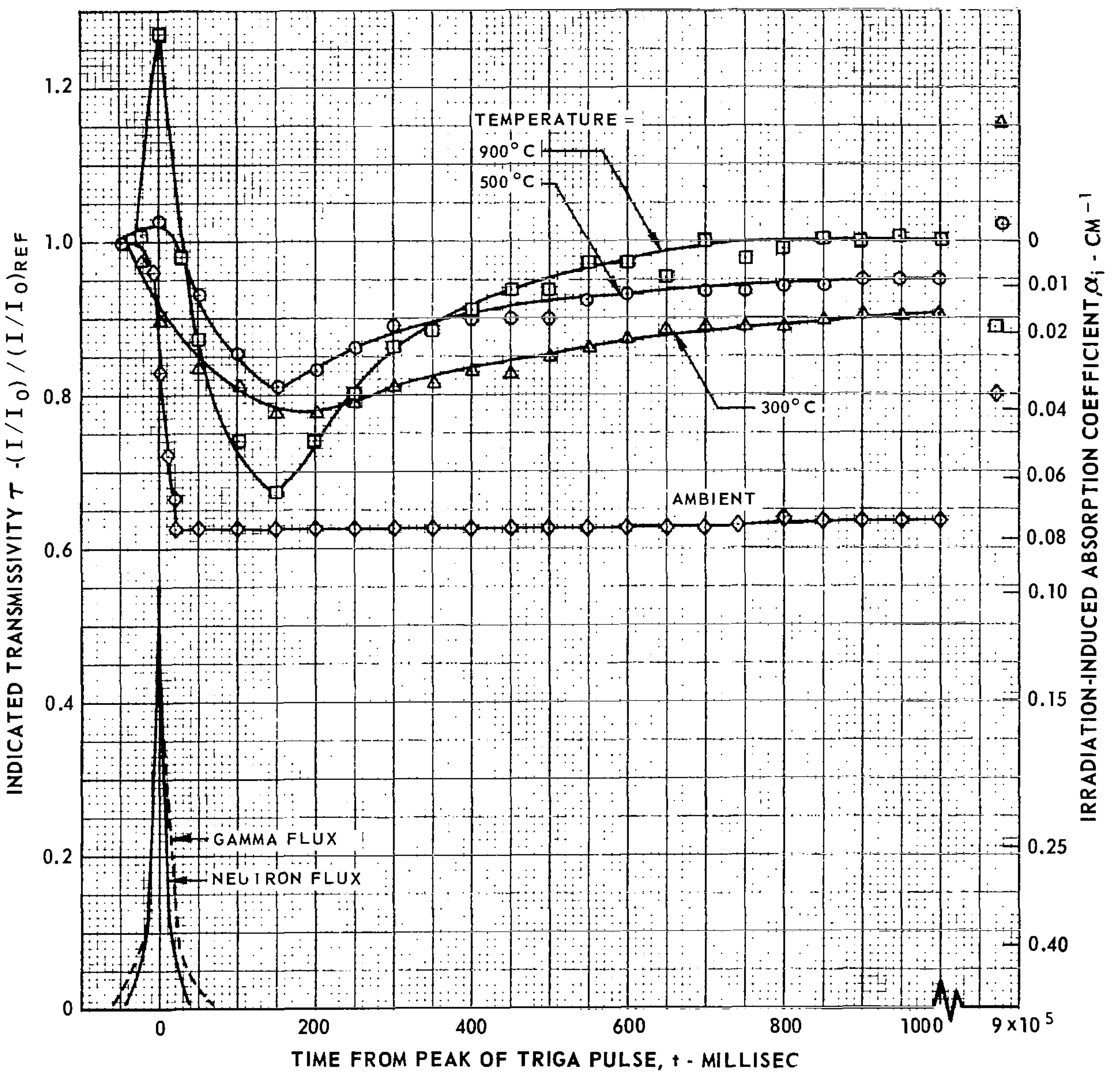
SUMMARY OF ABSORPTION COEFFICIENT RESULTS

Run	Specimen Temperature Degrees Centigrade	Wavelength Angstroms	Specimen	Preconditioning	Absorption Coefficient at peak of pulse cm^{-1}
B-12	500	2150	SC62-8	Unannealed	.0275
B-14	700	"	"	"	.0159
B-18	900	"	"	"	-
B-8	500	3021	"	Unannealed	.0029
B-16	700	"	"	"	0
B-20	900	"	"	"	.0039
C-3	700	2150	SC62-11	Annealed	.017
C-5	"	"	"	"	.025
C-7	"	"	"	"	.018
C-9	"	"	"	"	.015
D-2	700	2150	SC62-9	Unannealed	.024
D-4	"	"	"	"	.023
D-6	"	"	"	"	.009
D-8	"	"	"	"	.029
G-1	500	2150	SC62-13	Annealed	.016
G-3	700	"	"	"	.012
G-5	900	"	"	"	.009
G-7	900	"	"	"	.012
G-9	500	"	"	"	.014

COMPARISON OF TRANSMISSIVITIES AT DIFFERENT TEMPERATURES

WAVELENGTH, λ = 0.215 MICRON

SYMBOL	SPECIMEN	RUN (REF 1)	TEMPERATURE
◇	SC 62-2	B-1	AMBIENT
△	SC 62-5	E-8	300° C
⊙	SC 62-5	E-1	500° C
⊡	SC 62-5	E-5	900° C



OPTICAL SCHEMATIC FOR IN-REACTER TRANSMISSION MEASUREMENTS

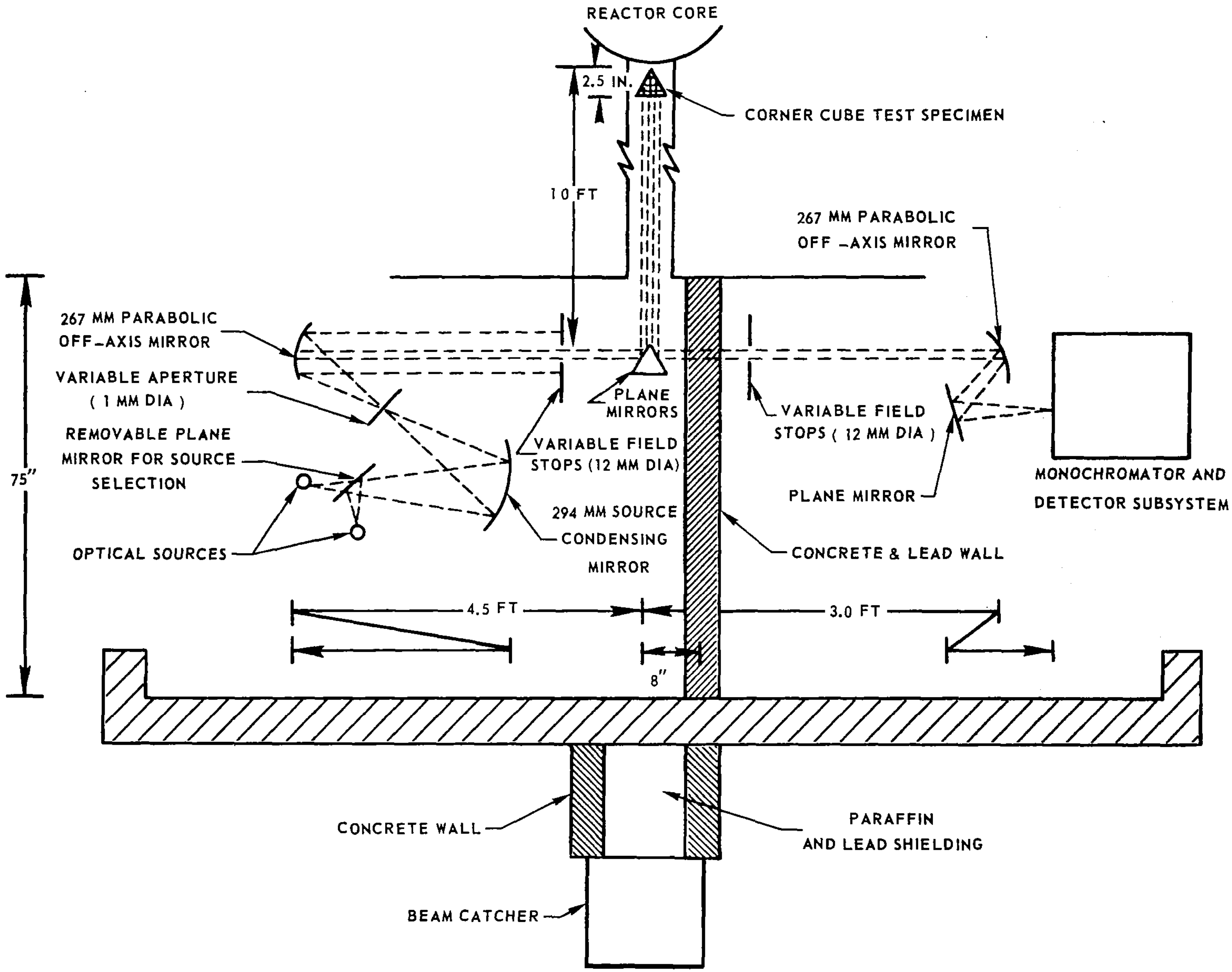


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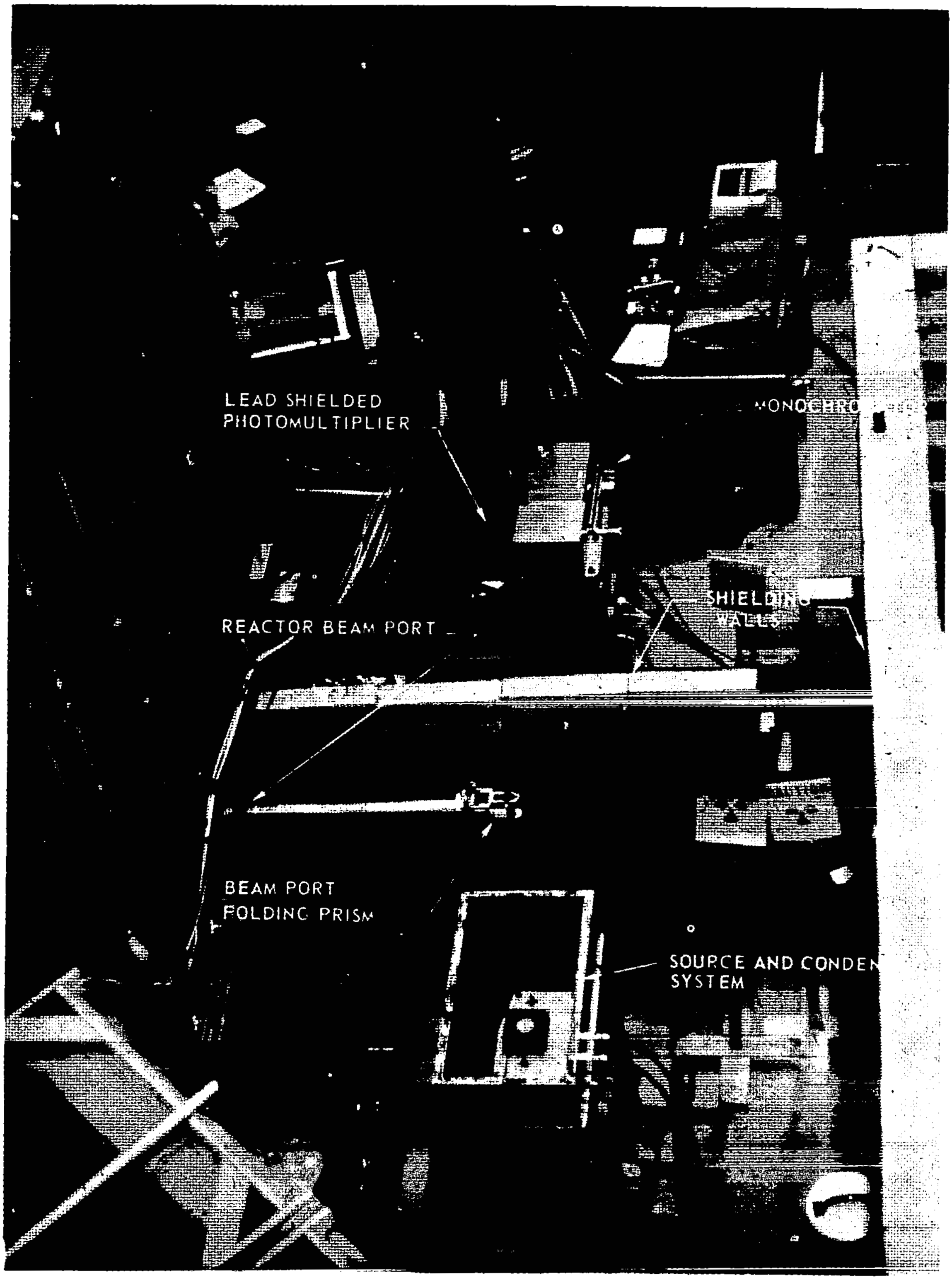
FIG. 2

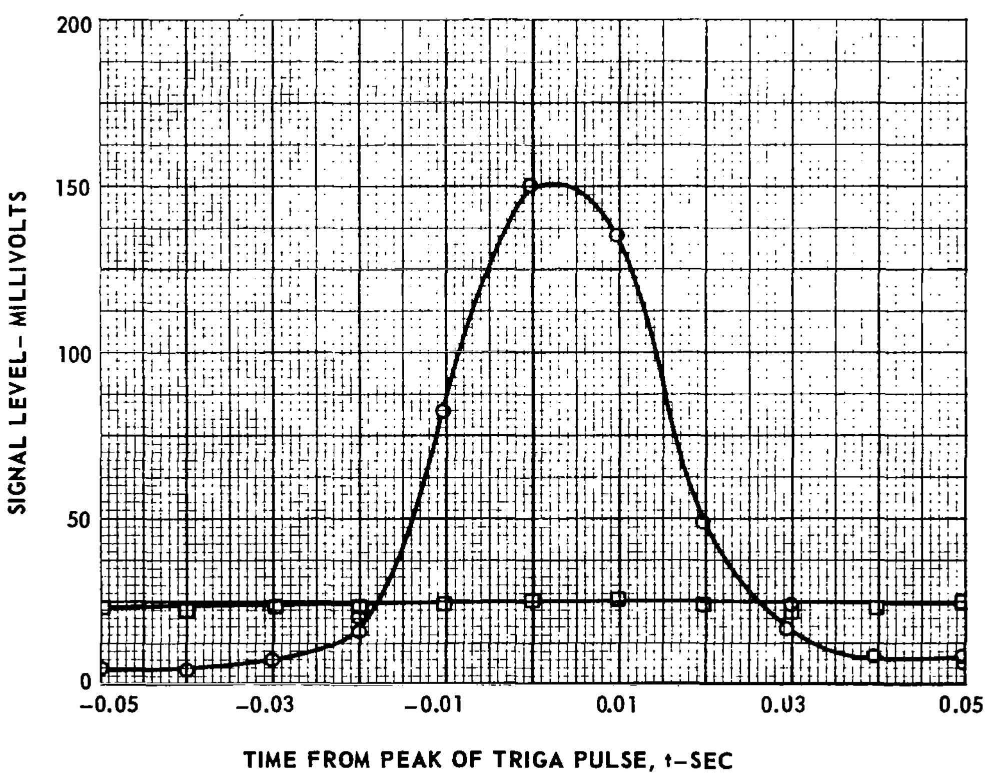
FIG. 3

OPTICAL INSTRUMENTATION IN TRIGA REACTOR



EFFECT OF LOCATION OF PHOTOMULTIPLIER ON BYPASS SIGNAL LEVELS

SYMBOL	RUN	PHOTOMULTIPLIER LOCATION
O	A-6	AT MONOCHROMATOR
□	A-7	OUTSIDE CONCRETE WALL



EFFECT OF SHIELDING ON BYPASS SIGNAL LEVELS

SYMBOL	RUN	TEST CONDITIONS
○	A-1	INITIAL CONDITIONS (AS IN REF. 1)
□	A-11	AFTER SHIELD WALL MODIFICATIONS

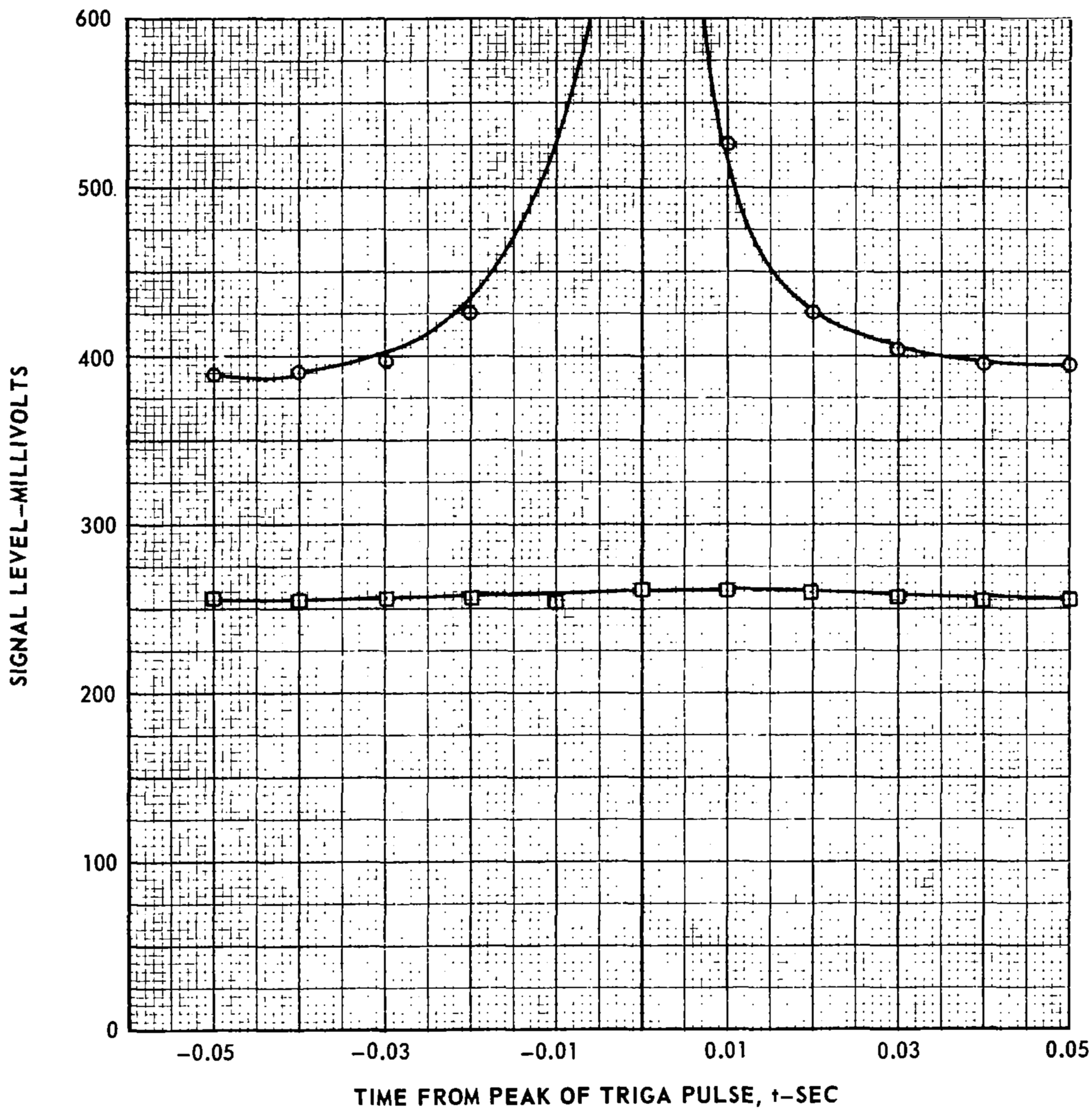


FIG. 6

REPEATABILITY OF FLUORESCENT SIGNAL LEVEL DURING RUNS C–1 THROUGH C–8

SPECIMEN SC62–11

TEMPERATURE 700°C

WAVELENGTH, λ 2150 Å

PRECONDITIONING: ANNEALED

SYMBOL	RUN
○	C–1
□	C–4
◇	C–6
△	C–8

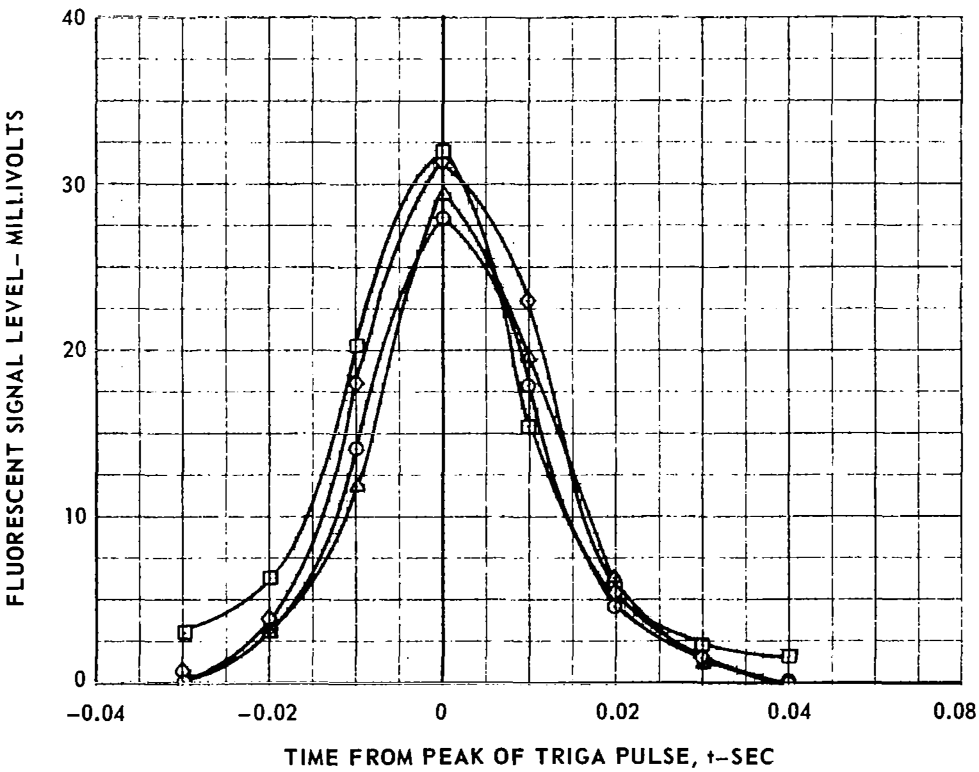


FIG. 7

EFFECT OF TEMPERATURE ON FLUORESCENT SIGNAL LEVEL

SPECIMEN SC62-8

WAVELENGTH, λ 2150 Å

PRECONDITIONING: UNANNEALED

SYMBOL	RUN	TEMPERATURE
○	B-11	500°C
□	B-13	700 °C
△	B-17	900°C

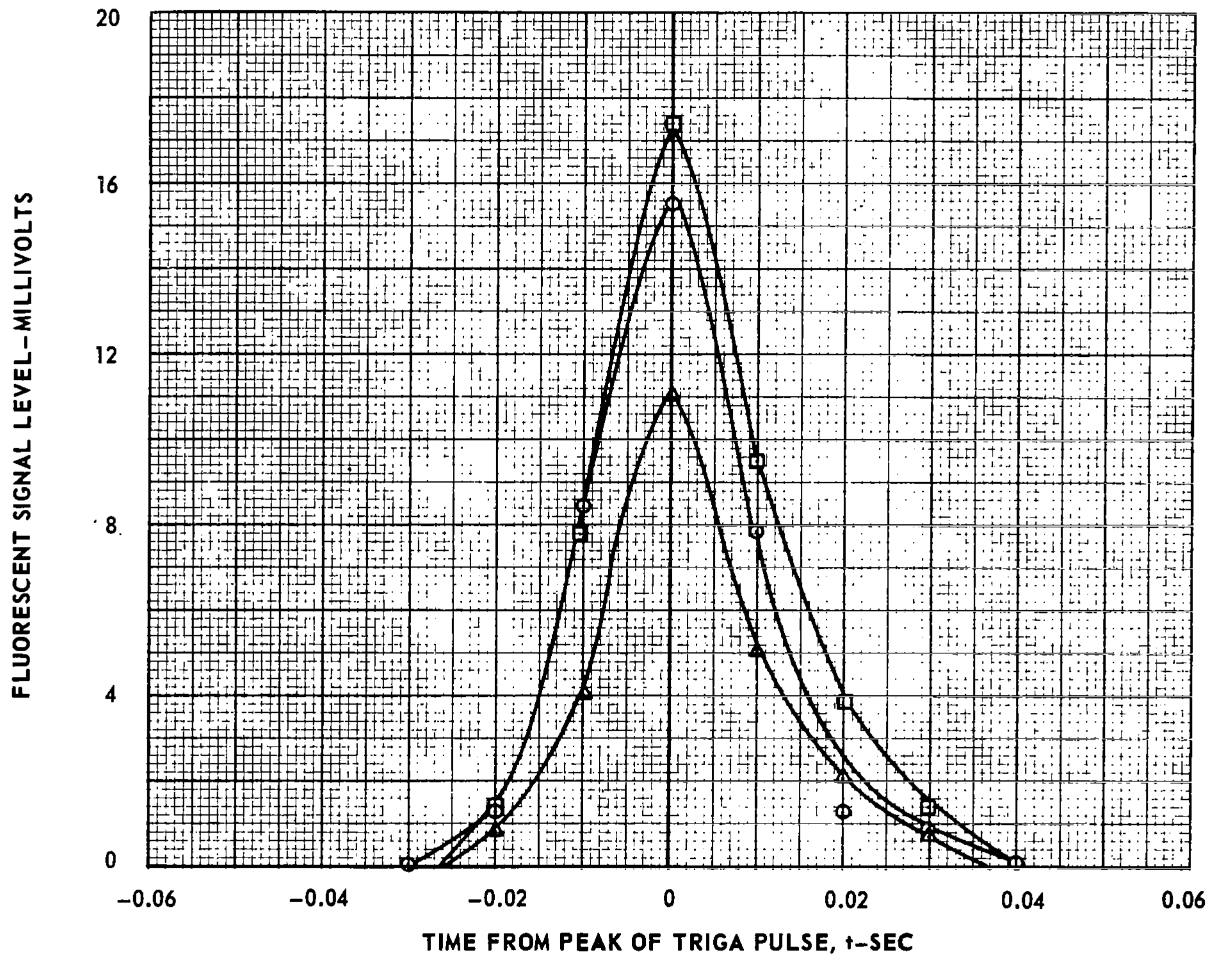


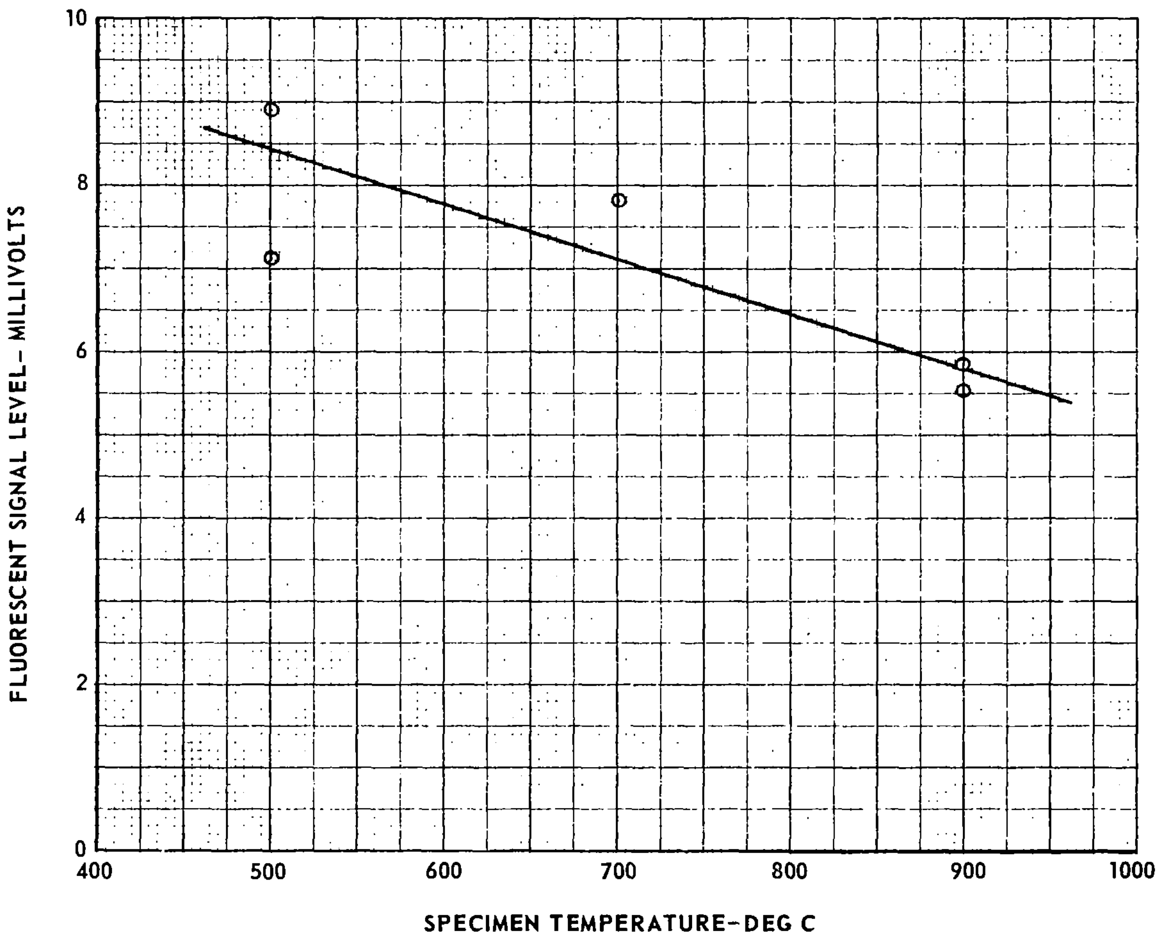
FIG. 8

EFFECT OF TEMPERATURE ON FLUORESCENT SIGNAL LEVEL AT PEAK OF TRIGA PULSE DURING RUN SERIES G

SPECIMEN SC62–13

WAVELENGTH ,λ 2150 Å

PRECONDITIONING: ANNEALED



EFFECT OF SPECIMEN MOUNTING CONFIGURATION ON TRANSMISSIVITIES DURING TEST RUNS

WAVELENGTH, λ 2150 Å

TEMPERATURE 700°C

SYMBOL	RUN	SPECIMEN	MOUNTING
O	E-1	SC62-12	3 POINT CONTACT
Δ	F-1	SC62-10	2 POINT CONTACT (ONE DELIBERATELY BROKEN)

DATA NOT CORRECTED FOR FLUORESCENCE

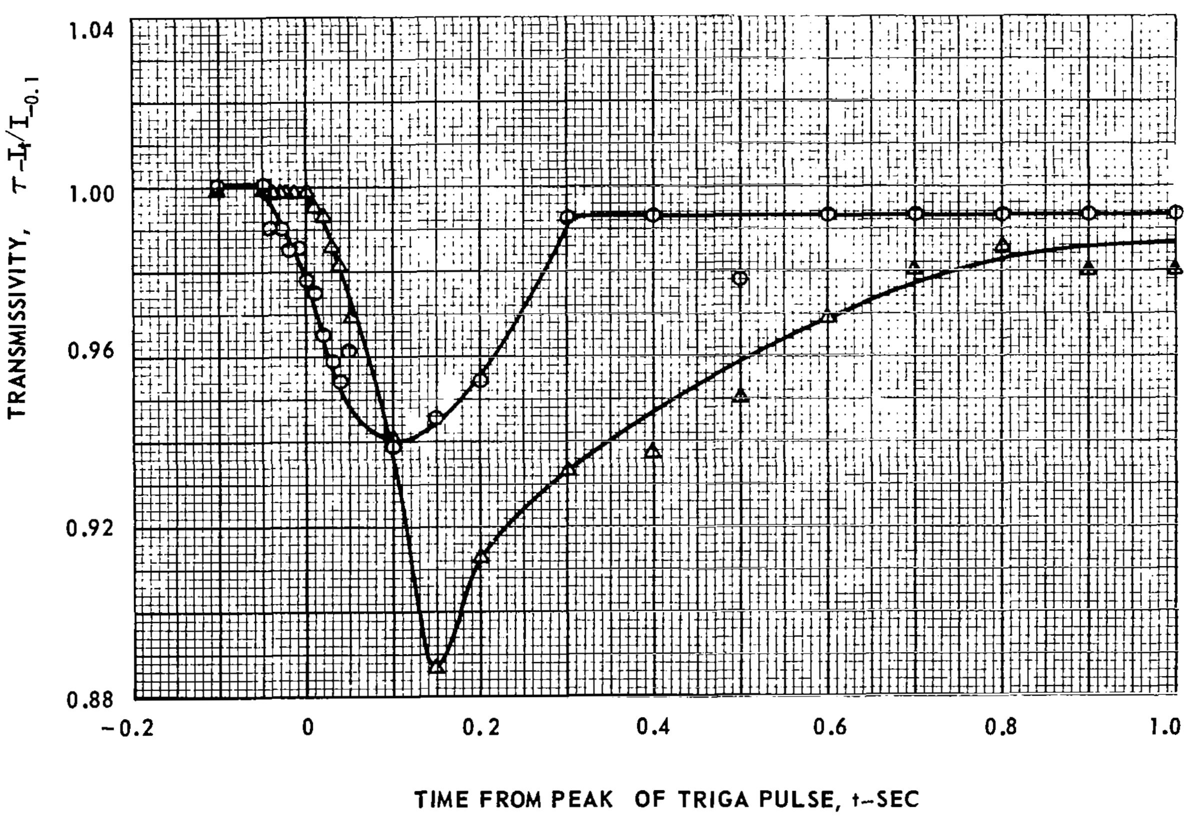


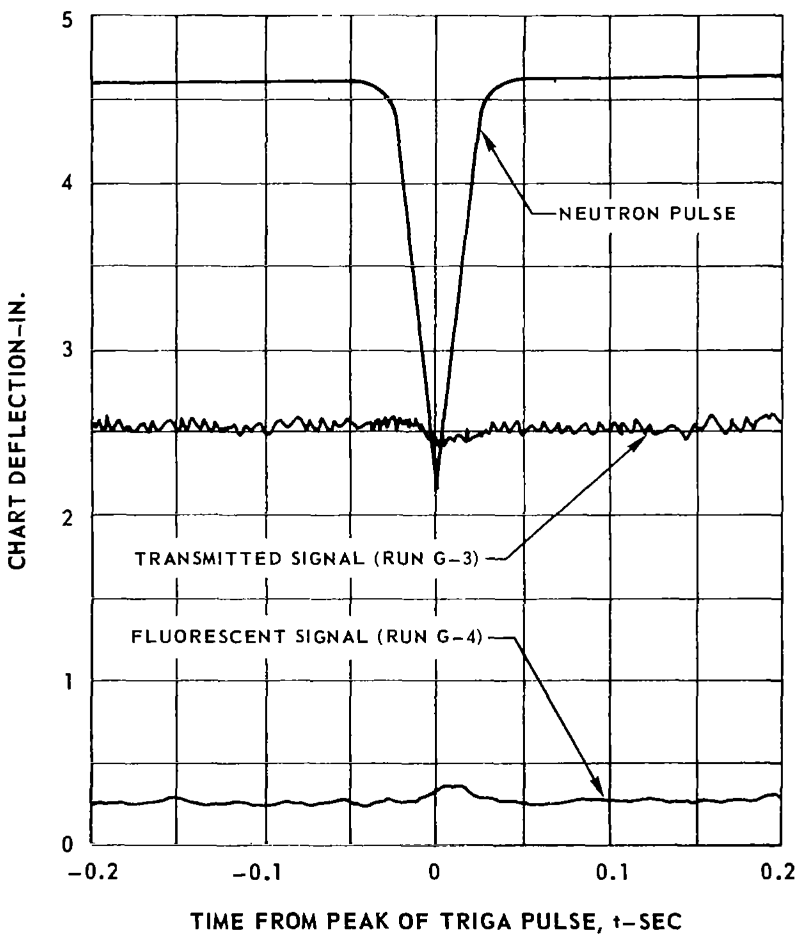
FIG. 10

TYPICAL SIGNAL LEVELS RECORDED DURING TRIGA PULSE

SPECIMEN SC62-13

WAVELENGTH, λ 2150 Å

TEMPERATURE 700°C



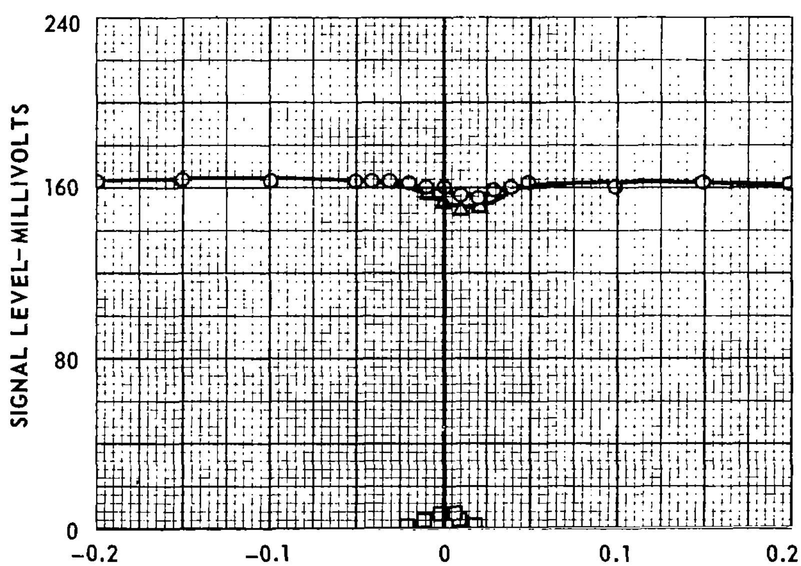
CORRECTED DATA FOR RUN G-3

SPECIMEN SC62-13

WAVELENGTH, λ 2150 Å

TEMPERATURE 700°C

SYMBOL	RUN	DESCRIPTION
○	G-3	TRANSMISSION
□	G-4	FLUORESCENCE
△	G-3 MINUS G-4	CORRECTED DATA

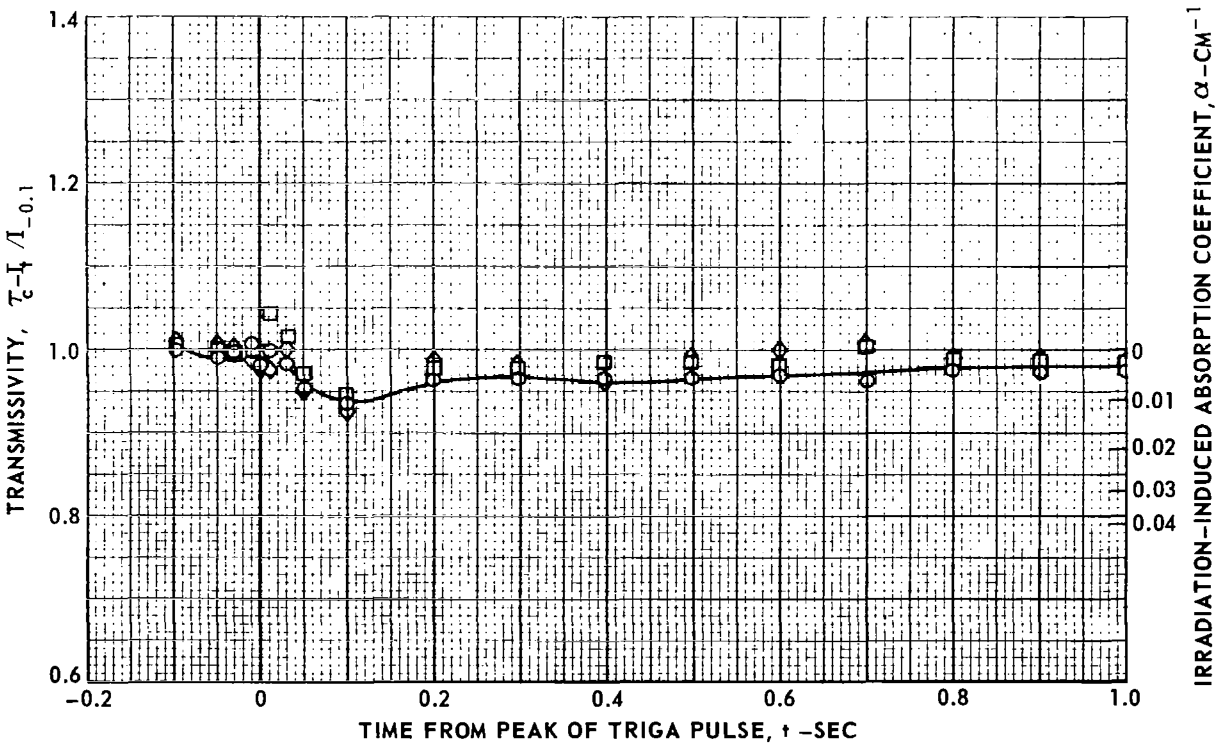


EFFECT OF TEMPERATURE UPON TRANSMISSIVITY AT 3021 ANGSTROMS DURING TRIGA PULSE

SPECIMEN SC62-8

PRECONDITIONING: UNANNEALED

SYMBOL	RUN	TEMPERATURE	FLUORESCENT RUN USED FOR CORRECTION	FLUORESCENT CORRECTION AT t = 0
○	B-8	500°C	B-9	0.125
□	B-16	700°C	B-15	0.18
◇	B-20	900°C	B-19	0.27



EFFECT OF TEMPERATURE UPON TRANSMISSIVITY AT 2150 ANGSTROMS DURING TRIGA PULSE

SPECIMEN SC62-8

PRECONDITIONING: UNANNEALED

SYMBOL	RUN	TEMPERATURE	FLUORESCENT RUN USED FOR CORRECTION	FLUORESCENT CORRECTION AT $t = 0$
○	B-12	500°C	B-11	0.17
□	B-14	700°C	B-13	0.28
◇	B-18	900°C	B-17	0.52

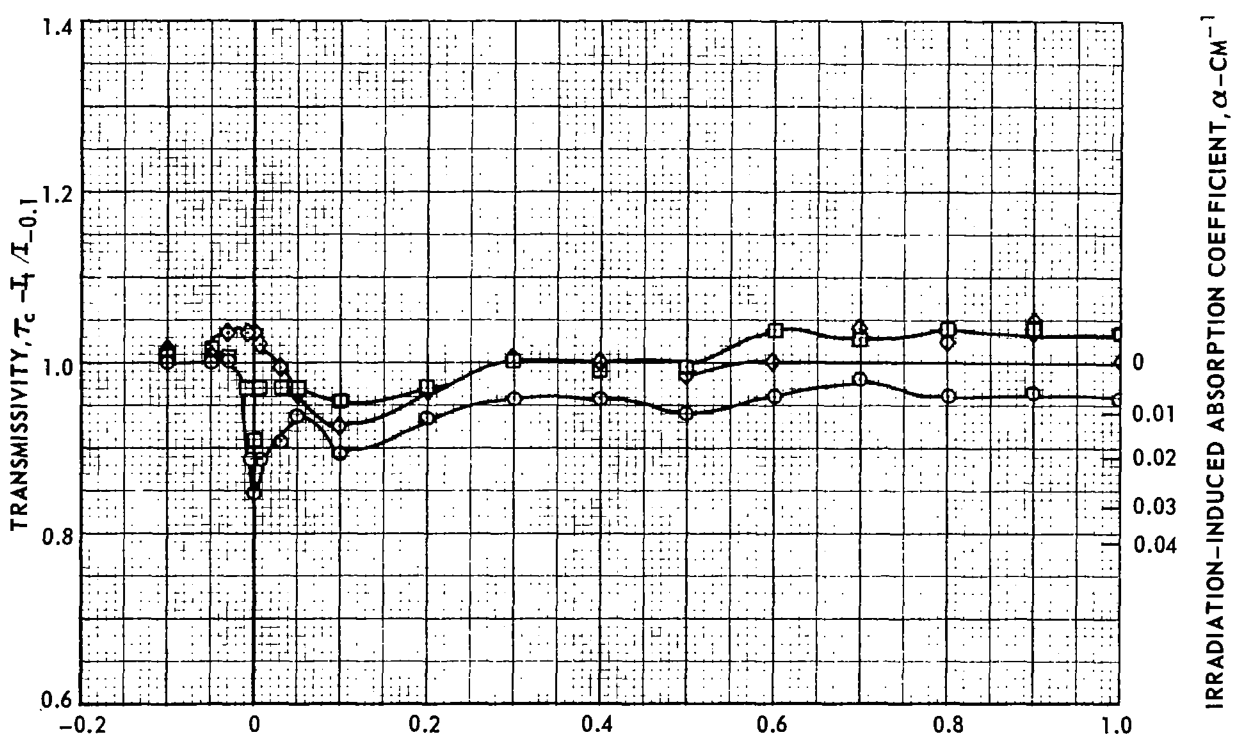


FIG. 14

REPEATABILITY OF TRANSMISSIVITY DURING RUNS C–3 THROUGH C–9 AT 700°C

SPECIMEN SC62–11

WAVELENGTH, λ 2150 Å

PRECONDITIONING: ANNEALED

SYMBOL	RUN	FLUORESCENT RUN USED FOR CORRECTION	FLUORESCENT CORRECTION AT t = 0
⊙	C–3	C–1	0.46
⊡	C–5	C–4	0.525
◇	C–7	C–6	0.525
△	C–9	C–8	0.44

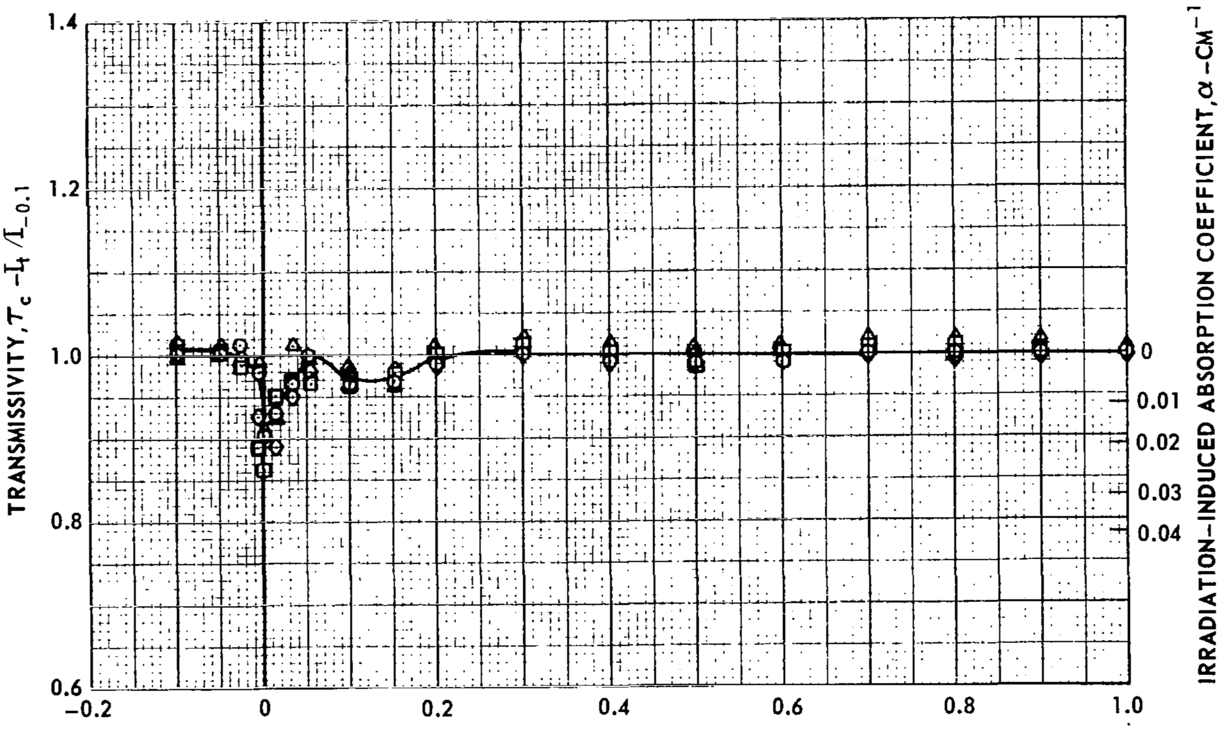


FIG. 15

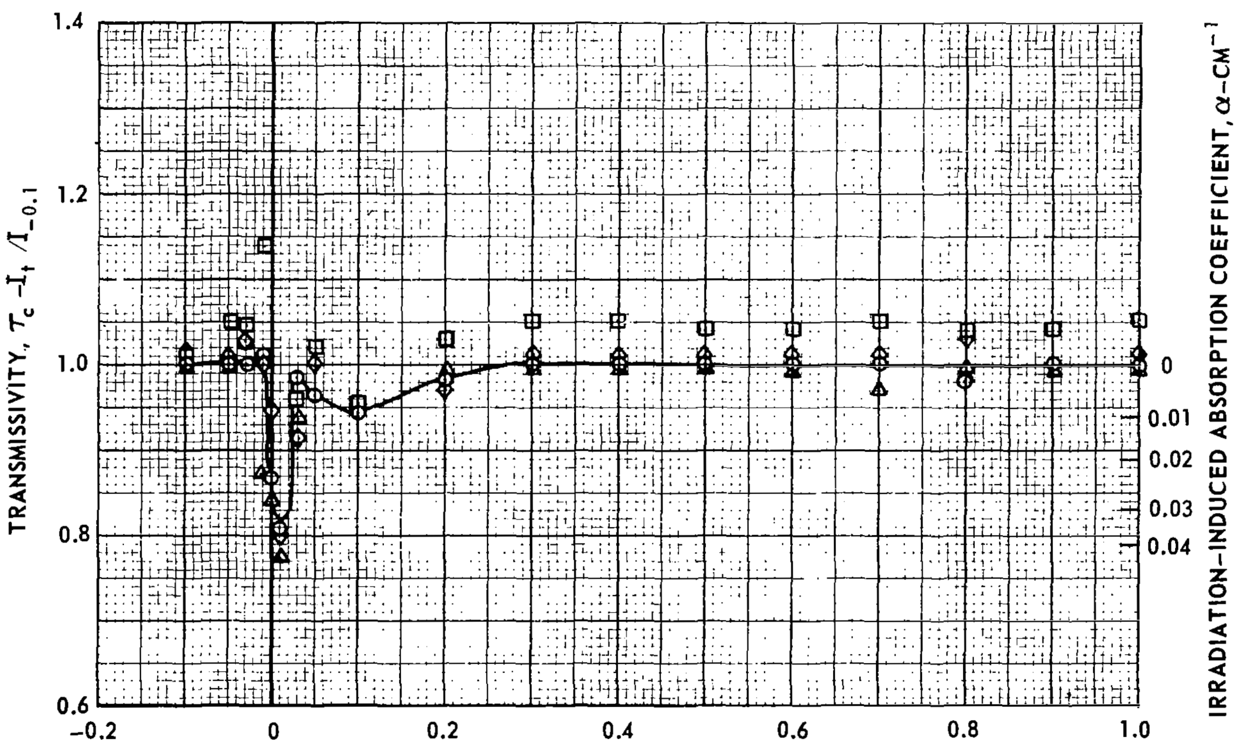
REPEATABILITY OF TRANSMISSIVITY DURING RUNS D-2 THROUGH D-8 AT 700°C

SPECIMEN SC62-9

WAVELENGTH λ 2150 Å

PRECONDITIONING: UNANNEALED

SYMBOL	RUN	FLUORESCENT RUN USED FOR CORRECTION	FLUORESCENT CORRECTION AT $t = 0$
⊙	D-2	D-1	0.705
⊡	D-4	D-3	1.10
◊	D-6	D-5	1.00
△	D-8	D-7	1.17



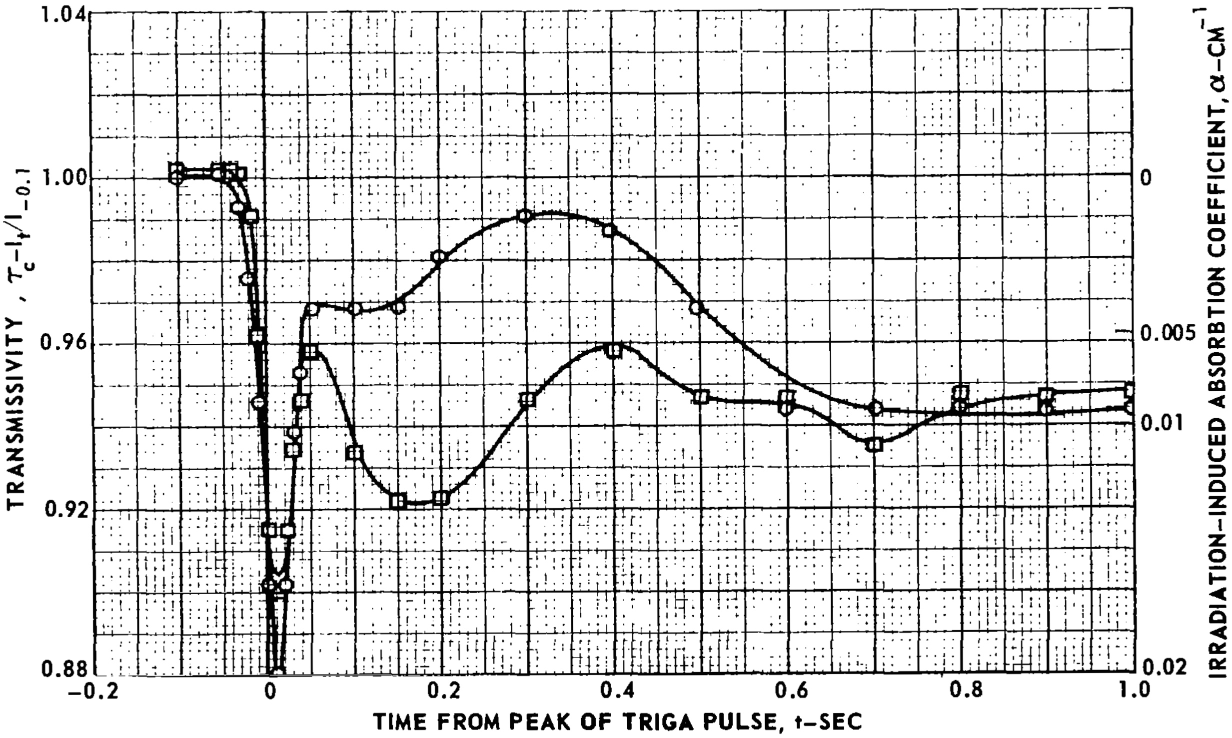
COMPARISON OF TRANSMISSIVITY DURING RUNS AT 500°C WITH INTERVENING PULSES

SPECIMEN SC62-13

WAVELENGTH, λ 2150 Å

PRECONDITIONING: ANNEALED

SYMBOL	RUN	FLUORESCENT RUN USED FOR CORRECTION	FLUORESCENT CORRECTION AT $t=0$
○	G-1	G-2	0.045
□	G-9	G-10	0.055



COMPARISON OF TRANSMISSIVITY DURING CONSECUTIVE RUNS AT 900°C

SPECIMEN SC62-13

WAVELENGTH, λ 2150 Å

PRECONDITIONING: ANNEALED

SYMBOL	RUN	FLUORESCENT RUN USED FOR CORRECTION	FLUORESCENT CORRECTION AT t=0
O	G-5	G-6	0.075
□	G-7	G-8	0.080

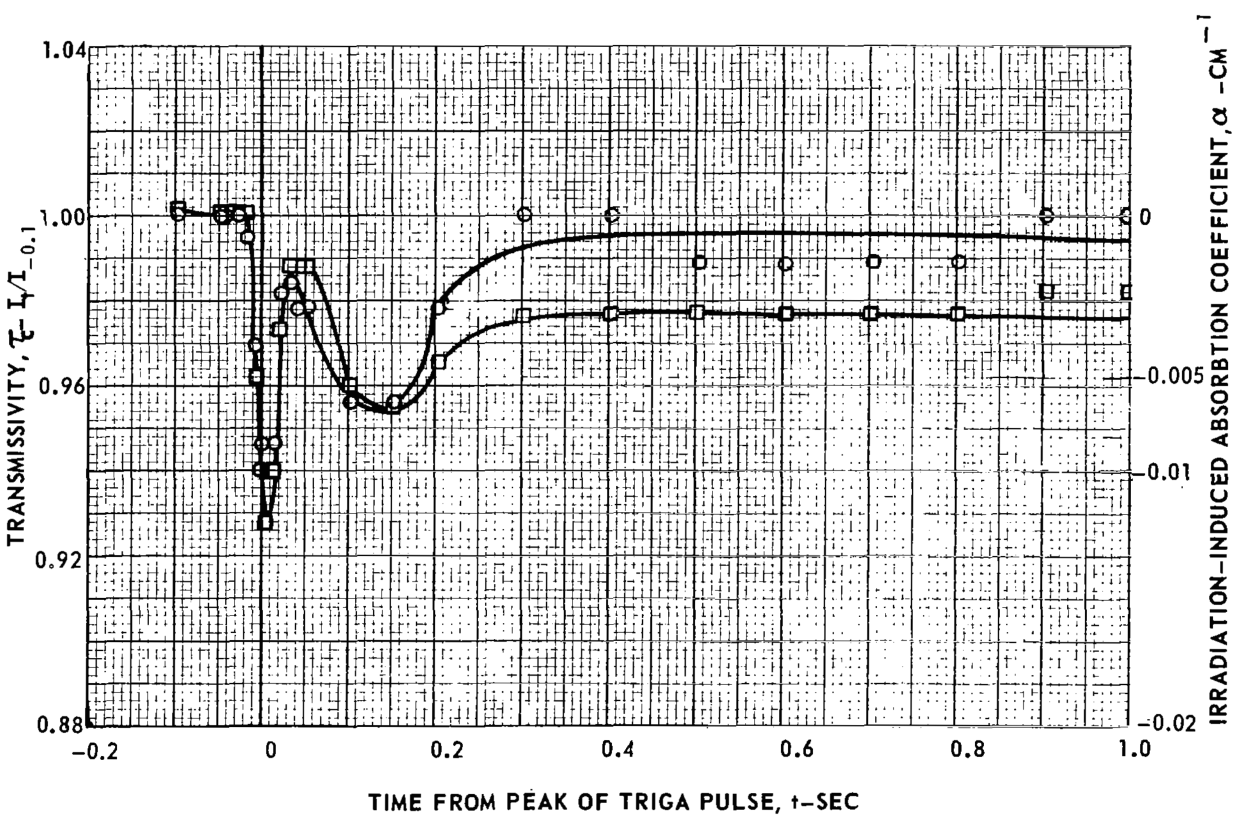


FIG. 18

EFFECT OF TEMPERATURE UPON TRANSMISSIVITY AT 2150 Å DURING TRIGA PULSE

SPECIMEN SC62-13

PRECONDITIONING: ANNEALED

SYMBOL	RUN	TEMPERATURE	FLUORESCENT RUN USED FOR CORRECTION	FLUORESCENT CORRECTION AT t = 0
○	G-1	500°C	G-2	0.045
□	G-3	700°C	G-4	0.052
△	G-5	900°C	G-6	0.075

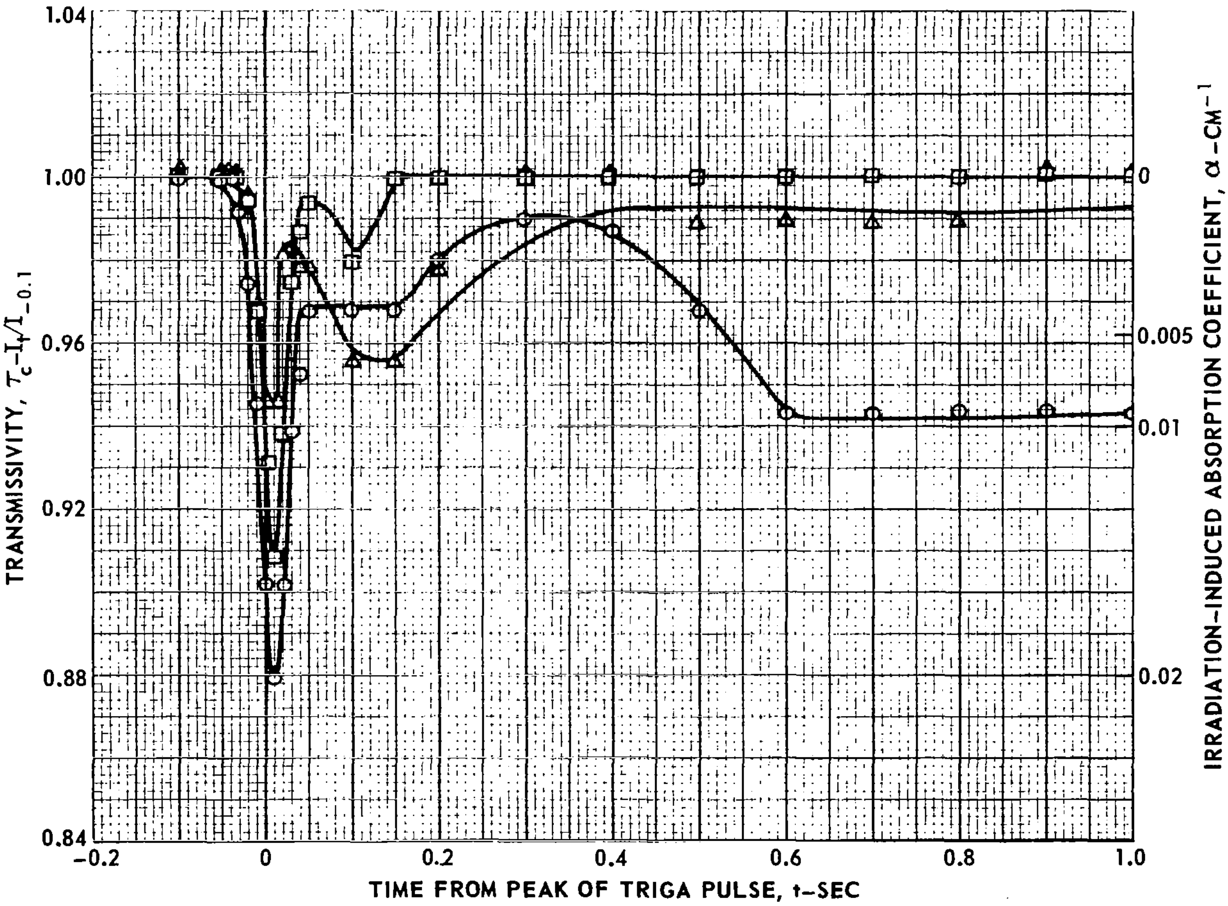
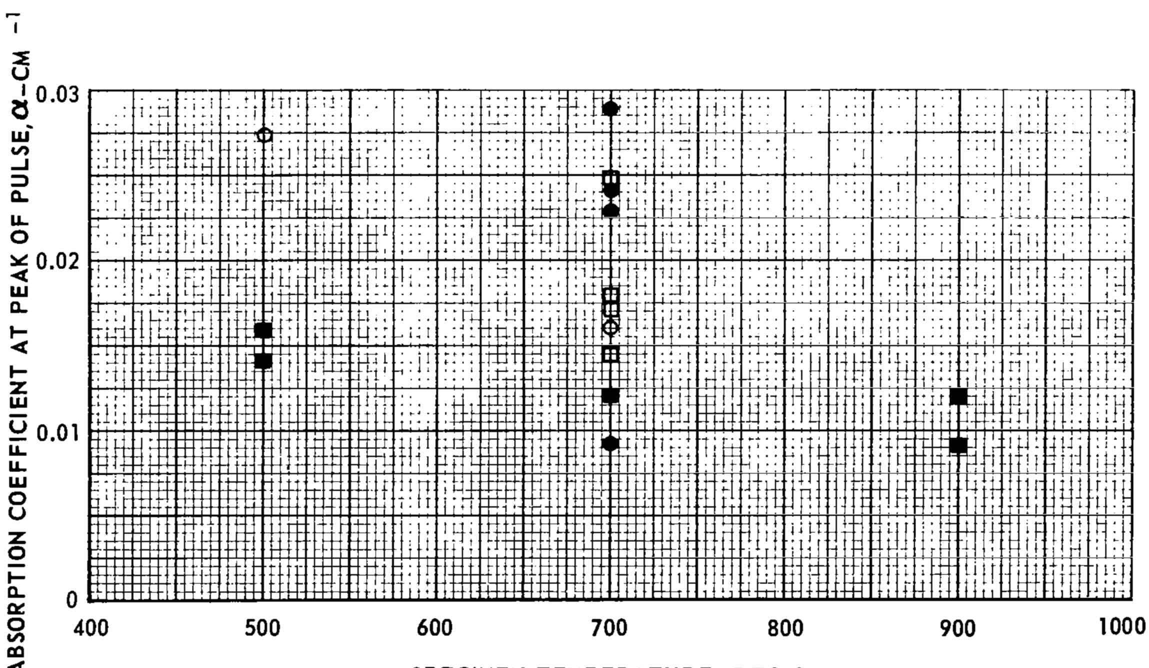


FIG. 19

EFFECT OF TEMPERATURE ON ABSORPTION COEFFICIENT AT PEAK OF TRIGA PULSE

* WAVELENGTH, λ 2150 Å

SYMBOL	SERIES	SPECIMEN	PRECONDITIONING
○	B	SC62-8	UNANNEALED
●	D	SC62-9	UNANNEALED
□	C	SC62-11	ANNEALED
■	G	SC62-13	ANNEALED



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